

3D spectroscopy as a tool for investigation of the BLR of lensed QSOs

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Summary. Selective amplification of the line and continuum source by microlensing in a lensed quasar can lead to changes of continuum spectral slopes and line shapes in the spectra of the quasar components. Comparing the spectra of different components of the lensed quasar and the spectra of an image observed in different epochs one can infer the presence of millilensing, microlensing and intrinsic variability. Especially, microlensing can be used for investigation of the unresolved broad line (BLR) and continuum emitting region structure in active galactic nuclei (AGN). Therefore the spectroscopic monitoring of selected lensed quasars with 3D spectroscopy open new possibility for investigation of the BLR structure in AGN. Here we discuss observational effects that may be present during the BLR microlensing in the spectra of lensed QSOs

1 Introduction

Gravitational lensing is in general achromatic (the deflection angle of a light ray does not depend on its wavelength); however, the wavelength-dependent geometry of the different emission regions may result in chromatic effects (see Popović & Chartas 2005, and references therein). Studies aimed at determining the influence of microlensing on the spectra of lensed quasars (hereafter QSOs) need to account for the complex structure of the QSO central emitting region. Since the sizes of the emitting regions are wavelength-dependent, microlensing by stars in a lens galaxy will lead to a wavelength-dependent magnification. The geometries of the line and the continuum emission regions are in general different and there may be a variety of geometries depending on the type of AGN (i.e. spherical, disc-like, cylindrical, etc.). Observations and modeling of microlensing of the broad-line region (BLR) of lensed QSOs are promising, because the study of the variations of the broad emission-line shapes in a microlensed QSO image could constrain the size of the BLR and the continuum region.

Our knowledge of the inner structure of quasars is very limited and largely built on model calculations. Continuum-line reverberation experiments with

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low-redshift QSOs tell us that the broad-emission line region (BLR) is significantly smaller than earlier assumed, and it is typically several light days up to a light year across (e.g., Kaspi et al. 2000). It means that the BLR radiation could be significantly amplified due to microlensing by (star-size) objects in an intervening galaxies (Abajas et al. 2002). Hence, gravitational lensing can provide an additional method for studying the inner structure high-redshift quasars for several reasons:

- (i) the extra flux magnification, from a few to 100 times, provided by the lensing effect enables us to obtain high signal-to-noise ratio (S/N) spectra of distant quasars with less observing time;
- (ii) the magnification of the spectra of the different images may be chromatic (as was noted in Wambsganss & Paczyński 1991, Wisotzki et al. 2003, Wucknitz et al. 2003, Popović & Chartas 2005) because of the line and continuum emitting region are different in sizes and geometrically complex and/or complex gravitational potential of lensing galaxy; (iia) consequently, microlensing events lead to wavelength-dependent magnifications of the continuum that can be used as indicators of their presence (Wisotzki et al. 2003, Popović & Chartas 2005);
- (iii) gravitational microlensing can also change the shape of the broad lines (see Popović et al. 2001, Abajas et al. 2002, Popović & Chartas 2005), the deviation of the line profile depends on the geometry of the BLR.

Finally, the monitoring of lensed QSOs in order to investigate the effect of lensing on the spectra can be useful not only for constraining the unresolved structure of the central regions of QSOs, but also for providing insight to the complex structure of the lens galaxy.

2 Structure of the central part of AGNs and probability of the BLR microlensing

According to the standard model of AGNs, a QSO consists of a black hole surrounded by a (X-ray and optical) continuum emitting region probably with an accretion disk geometry, a broad line region (BLR) and a larger region, narrow line region (NLR) that can be resolved in several nearby AGNs (e.g., Krolik 1999). The physics and structure of the NLR have been investigated using the observations of the region in nearby AGNs, while the physics and structure of the BLR cannot be investigated by direct observations. Our knowledge of the inner structure of quasars is very limited and largely built on model calculations. Continuum-line reverberation experiments (in the UV/optical spectral band) with low-redshift QSOs tell us that the broad-emission line region (BLR) is significantly smaller than earlier assumed, and it is typically several light days up to a light year across (e.g., Kaspi et al. 2000).

Consequently, one can expect that the magnification of the BLR (or a part of the BLR) and continuum emission due to microlensing. In Fig. 1 (left),

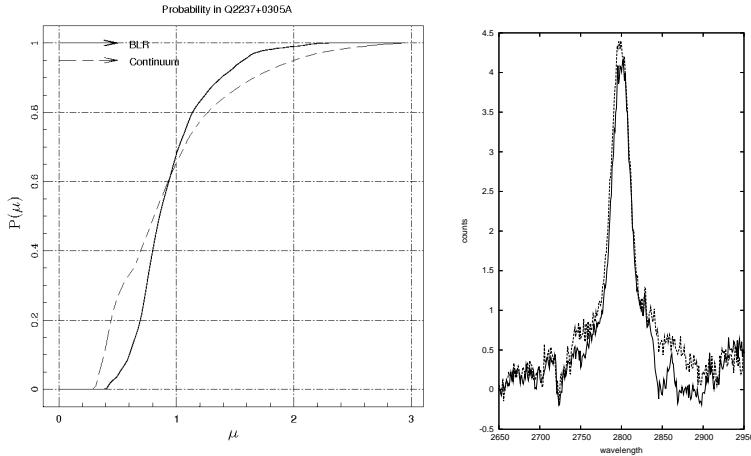


Fig. 1. *Left:* Accumulate probability of the magnification of the BLR, in solid line, and the continuum, in dashed line (Abajas et al. 2005). *Right:* Comparison of the line shape of Mg II $\lambda=2798$ Å of SDSS J0924+0219 observed at two epochs; 15/01/2005 – solid line, and 01/02/2005 – dashed line (Eigenbrod et al. 2005)

the cumulative probabilities for microlensing of the BLR and continuum as a function of the ERR (in units of the BLR dimensions) are given. As one can see in Fig. 1 (left), there is a global correlation between the BLR and continuum microlensing probabilities, i.e. one can expect that the variation in the line profile of a QSO should be also seen as amplification in the continuum. We should note here that the emission of the BLR can be partially amplified due to microlensing, i.e. one part of the BLR can be affected by microlens that can result in amplification of the only one part of broad lines (see Fig 1, right)

3 3D spectroscopy as tool for the BLR investigation

A systematic search for microlensing signatures in the spectra of lensed quasars should be performed with 3D spectroscopy. One of examples is the Cosmological Monitoring of Gravitational Lenses (COSMOGRAIL, see Eigenbrod et al. 2005). To detect microlensing, simultaneous observations of spectra of images of a lensed QSO at several epochs, preferably separated by the time-delay, are needed (see Popović & Chartas 2005).

Taking into account the redshift of lensed QSOs it is needed to obtain the spectra from 3500 to 9000 Å (covering also, the broad C IV, CIII] and Mg II lines which are emitted from the BLR region) of a sample multi-imaged QSOs. Concerning the estimation of the BLR dimensions (see Kaspi et al. 2000), one should select a sample of lensed QSOs where the BLR microlensing might be expected. To find the possible microlensing one can

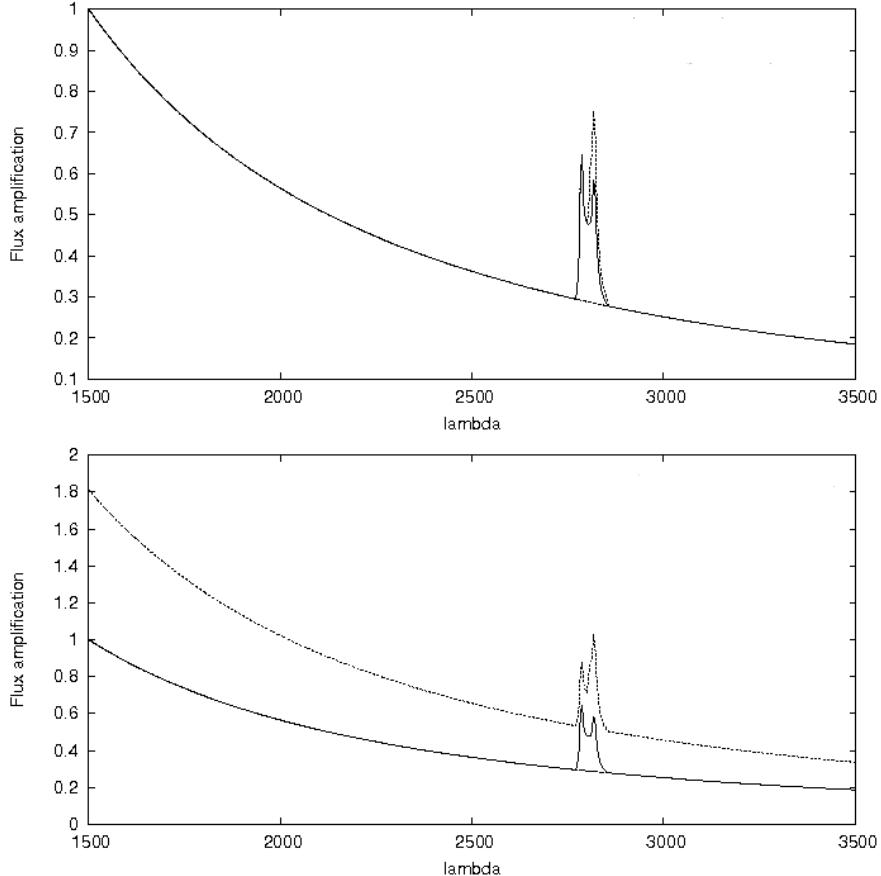


Fig. 2. The simulation of the variation in Mg II $\lambda = 2798\text{\AA}$ and the continuum between 1500 \AA and 3500 \AA due to microlensing by straight fold caustic. The microlensing may affect only line profile (top) as well as the line profile and the continuum (down).

apply the method given by Popović & Chartas (2005) comparing the spectra (in the continuum and in the broad lines) of different components in order to detect the difference caused by microlensing or/and millilensing. Using previous theoretical estimates of line shape variations due to microlensing (Popović et al. 2001, Abajas et. al. 2002, 2005, Popović & Chartas 2005) the observed spectra can be fitted with the theoretical line profile assuming different geometries. From this one will be able to estimate the geometry and dimension of the BLR. Also, comparing difference in amplification of the continuum, C IV and Mg II lines one will be able to conclude about differences between high and low ionized line emitting regions and compare them with the size and geometry of the continuum emission region.

4 Microlensing of the BLR/continuum emission

Let us discuss the expected variability in the line and continuum shapes due to microlensing. Recently, the broad line variability that may be caused by microlensing were observed by Richards et al. (2004) and Eigenbrod et al. (2005). Concerning the theoretical predictions (see Popović et al. 2001, Abajas et al. 2002) one can expect that different parts of a line can be amplified and that the line should change in intensity as well as in the shape during the microlensing event. Also, the continuum should vary (Lewis & Ibata 2004) and there is a correlation between the continuum and line amplification (see Fig. 1, left). Also, it is expected that the continuum emission is wavelength dependent (Popović & Chartas 2005). But, all of these effects might not be seen at the same time of a microlensing event. As an example in Fig. 2 (top) we present simulation of microlensing of an emission from the accretion disk, taking that the continuum is coming from the inner part of the disk (from 50 R_g to 200 R_g) and the Mg II line from the outer part (from 200 R_g to 1200 R_g). The used model of the disk is the same as it is given in Popović et al. (2005), but with $i = 14^\circ$ and for the UV radiation. In some cases the continuum can remain constant, while the line can be amplified. It corresponds to the case where only the outer part of the disk is microlensed (the part that emits the line). Such amplification of a line without amplification of the continuum can be seen only for a limited period of time. But during a complet microlensing event the continuum should be also amplified (see Fig 2, down). Consequently, to register the microlensing presence, one should monitor lensed QSOs using 3D spectroscopy in order to have observations of all images at the same time from different epochs.

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